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TEST AND EVALUATION OF ARIZONA SLIP-AWAY BASE LUMINAIRE SUPPORTS

Final Report

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16. Abstract

A study was undertaken to evaluate the impact performance of ADOT's slip-away base luminaire supports. For purposes of this evaluation, three full-scale crash tests were conducted in accordance with the requirements of *NCHRP Report 350*. During this test program, ADOT's 13.7-m (45-ft) constant tapered luminaire support was found to exhibit unacceptable impact performance. Although the slip base activated readily and the occupant impact velocity was within recommended limits, a secondary impact of the pole with the roof of the vehicle resulted in substantial deformation of the roof structure. A subsequent test of ADOT's standard 12.2-m (40-ft) luminaire system was judged to be marginally acceptable. Although the luminaire support readily yielded to the vehicle and the occupant risk criteria were well within the recommended limits established by *NCHRP Report 350*, the test vehicle once again sustained substantial deformation to the roof structure from a secondary impact with the luminaire pole. However, the magnitude and localized extent of the crush was judged to be within acceptable limits based on results of other approved systems.

Several candidate systems were identified which provide a mounting height of 13.7 m (45 ft) or greater and which could serve as replacements for ADOT's deficient 13.7-m (45-ft) poles. The most promising of these is a steel 4-bolt slip-base design developed by the Utah Department of Transportation (UDOT) which has a mounting height of 15.8 m (52 ft) and was successfully crash tested. As an alternative to adopting a new design, it is also recommended that the current design requirements be carefully reviewed and options for reducing the weight of the existing system be considered.

Maintenance practices related to slip-bolt torque were also reviewed. Although no specific post-installation inspection procedure for slip-base bolt torques is offered at this time, periodic visual inspections of slip-base poles should be considered to determine if debris, soil, corrosion, erosion, or other hindrances that could compromise proper actuation of the slip-base are present. It was also noted that although proper performance of slip-base supports depends on the clamping force in the slip-base bolts, crash tests and analytical studies indicate that the performance is not overly sensitive to the clamping force.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.452	centimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3.

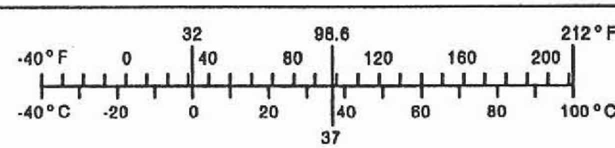
Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

These factors conform to the requirement of FHWA Order 5190.1A

*SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
yd	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
yd^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	millimeters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

Roadside safety appurtenances continue to evolve in response to advancements in technology and materials. As significant improvements in impact performance are attained, state highway agencies are compelled to periodically reevaluate their standards and make changes when appropriate. Toward this goal, the Arizona Department of Transportation (ADOT) recently conducted a review of their standard highway safety appurtenances (1). As a result of this review, several standard ADOT appurtenances were recommended for further evaluation through full-scale testing to verify their conformance with current impact performance guidelines. Included in this list of appurtenances were ADOT's standard luminaire pole and slip-away base combinations.

Although some of the lighter slip base/pole combinations appear to be acceptable based on previous crash tests of similar designs (2), there was some concern regarding the impact performance of some of the taller, heavier poles. Furthermore, the ADOT triangular slip-base design does differ slightly from those previously tested in terms of slip base bolt size, bolt circle, and bolt torque. Slip-base designs can be sensitive to such design details and the effects of these changes on safety performance is difficult to ascertain except through full-scale crash testing.

Thus, one of the primary objectives of this study was to verify the crash worthiness of ADOT's slip-away bases (ADOT standard drawings T.S. 5-2 and 5-3) for use with ADOT's standard 9.1-m (30-ft), 12.2-m (40-ft), and 13.7-m (45-ft) luminaire poles (ADOT standard drawings T.S. 4-4, 4-7, 4-8, and 4-9). In addition, maintenance practices related to slip-bolt torque were reviewed.

RESEARCH APPROACH

ADOT's lighting pole standards, as contained in the 1985 ADOT Traffic Signals and Lighting Standard Drawings, include 9.1-m (30-ft) poles (detailed in standard ADOT drawing T.S. 4-4 and 4-7), 12.2-m (40-ft) poles (T.S. 4-8), and 13.7-m (45-ft) poles (T.S. 4-9). For each of these heights there are at least two alternate designs: a step tapered option which consists of three different sizes of pipe connected with specially fabricated reducing sections, and a constant taper option which has a uniform thickness and a specified taper rate. These poles are mounted on one of two slip-base designs. The 9.1-m (30-ft) poles are mounted on a slip-away base detailed in standard drawing T.S. 5-2. The 12.2 (40) and 13.7-m (45-ft) poles are used in combination with the base detailed in T.S. 5-3.

An assessment of ADOT's luminaire pole/slip base combinations was conducted to identify which systems are likely to be most critical in terms of impact performance. For a given slip-base design, the impact performance is known to be sensitive to the total mass of the luminaire system. The estimated weight of ADOT's standard luminaire pole/slip base combinations is shown in Table 1. The weights presented in this table are representative of the total weight of the installation including pole, pole base plate, mast arm, and luminaire.

Table 1. Estimated Weight of ADOT Luminaire Pole/Slip Base Combinations.

Standard Drawing #	Pole Type	Pole Length m (ft)	Weight[(a)] kg (lb)	
			Constant Taper	Step Taper
T.S. 4-4	D	9.1 (30)	283.5 (625)	265.3 (585)
T.S. 4-7	G	9.1 (30)	269.9 (595)	292.6 (645)
T.S. 4-8	H	12.2 (40)	385.6 (850)[(b)]	351.5 (775)
T.S. 4-9	J	13.7 (45)	452.2 (997)[(b)]	555.7 (1225)[(b,c)]

[(a)]Calculated weight includes pole, pole base plate, 6.1 m (20 ft) mast arm, and luminaire
[(b)]Measured weight of actual luminaire components
[(c)]Exceeds FHWA recommendations (4)

In a memorandum from the Federal Highway Administration (FHWA) to regional federal highway administrators dated July 16, 1990 (4), requirements pertaining to the use of steel slip-base luminaire supports on federal-aid highways were set forth. Contained within this set of requirements is a maximum weight restriction (including pole, base plate, mast arm, and luminaire) of 453.6 kg (1,000 lb). The reason for this limit is that tests of systems exceeding this weight have exhibited undesirable safety performance.

As shown in Table 1, ADOT's 13.7-m (45-ft) step-tapered pole exceeds the FHWA weight limit and it is therefore presumed that this system will display unacceptable impact performance. In light of this potential deficiency, the limited use of this system, and the availability of other systems which have similar mounting heights but less total mass, ADOT engineers agreed to eliminate the 13.7-m (45-ft) step-taper pole from ADOT standards. Testing of this system under this study was therefore not conducted.

The next most critical design in terms of total mass is the 13.7-m (45-ft) constant tapered luminaire pole. This system consists of a single tapered pole with a constant 7-gauge wall thickness. The total weight of the system with a 6.1-m (20-ft) mast arm and luminaire was measured to be 452.2 kg (997 lb) which is just under the recommended weight limit of 453.6 kg (1,000 lb) established by the FHWA memorandum (4). For this reason, the crashworthiness of this system was considered questionable and it was recommended that its impact performance be verified through full-scale testing.

The 13.7-m (45-ft) luminaire system was therefore selected for testing based on the premise that if it successfully passed the required impact criteria, that system, as well as all lighter ADOT systems supported on similar slip-base designs, would be considered crashworthy. That is, if the most critical system passes all test requirements, it is reasonable to assume that all lighter systems of similar design will also perform satisfactorily and no further testing would be necessary.

In the event that the 13.7-m (45-ft) pole was found to be deficient, the next most critical system (i.e., the 12.2-m (40-ft) constant tapered pole) would be tested. In addition, information pertaining to approved luminaire systems would be collected and alternatives suitable for replacement of the 13.7-m (45-ft) pole would be recommended.

Finally, installation and maintenance practices related to slip-bolt torque were reviewed. This was accomplished through written correspondence and telephone interviews with the Federal Highway Administration and standards and maintenance engineers of state highway agencies which currently utilize slip-base luminaire designs. The results of these efforts are summarized in the sections which follow.

CRASH TEST PROCEDURES

All crash tests were conducted and evaluated in accordance with *National Cooperative Highway Research Program (NCHRP) Report 350*, "Recommended Procedures for the Safety Performance Evaluation of Highway Features" (3), and the 1990 American Association of State Highway Transportation Officials (AASHTO) *Standards Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* (5).

NCHRP Report 350 recommends two tests to certify the crashworthiness of breakaway support structures: a low-speed test and a high-speed test. The low-speed test, test designation 3-60, involves an 820-kg (1,800-lb) passenger car impacting the support structure at a speed of 35 km/h (21.7 mi/h). This test is intended to evaluate the breakaway mechanism of the support. The high-speed test, test designation 3-61, involves an 820-kg (1,800-lb) vehicle impacting the support structure at 100 km/h (62.1 mi/h). The primary intent of this test is to evaluate vehicle and test article trajectory. Evaluation of occupant risk criteria and test object penetration into the occupant compartment are an important concern for both tests. Brief descriptions of the crash test and data analysis procedures used in the study are presented below.

Electronic Instrumentation and Data Processing

Each test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates; a triaxial accelerometer at the vehicle center-of-gravity to measure longitudinal, lateral, and vertical acceleration levels, and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. The accelerometers were strain gauge type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers and transducers were transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Provision was made for the transmission of calibration signals before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Pressure sensitive contact switches on the bumper were actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produced an "event" mark on the data record to establish the exact instant of contact with the luminaire support.

The multiplex of data channels, transmitted on one radio frequency, was received at a data acquisition station, and demultiplexed into separate tracks of Intermediate Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data was played back from the tape machines, filtered with a SAE J211 Class 180 filter, and were digitized using a microcomputer, for analysis and evaluation of impact performance. The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are given below.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-msec average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-msec intervals in each of the three directions are computed. Acceleration versus time curves for the longitudinal, lateral, and vertical directions are then plotted from the digitized data of the vehicle-mounted linear accelerometers using a commercially available software package.

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate charts to compute angular displacement in deg at 0.00067-s intervals and then instructs a plotter to draw a reproducible plot of yaw, pitch, and roll versus time. It should be noted that these angular displacements are sequence dependent with the sequence being yaw-pitch-roll for the data presented herein. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

An uninstrumented Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the vehicle.

Photographic Instrumentation and Data Processing

Photographic coverage of each test included two high-speed cameras. One camera was positioned to have a field of view perpendicular to and aligned with the luminaire support structure. A second camera was placed downstream of the luminaire support at an angle of approximately 45 degrees to impact. A flash bulb activated by pressure sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the support structure and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A professional video camera and a Betacam videotape recorder along with still cameras were used for documentary purposes and to record conditions of the test vehicle and test installation before and after the test.

Test Vehicle Propulsion and Guidance

The test vehicles were towed into the support structure using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicles was tensioned along the impact path, anchored at each end, and threaded through a guide plate attachment anchored to the front wheel of the test vehicle. Another steel cable was connected to the test vehicles, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2-to-1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the guardrail system, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring the vehicle to a safe and controlled stop.